Implementation Package: Emulsified Asphalt-Aggregate Mixtures - Mix Design and Design Coefficients

Physical Research Report No. 91

Illinois Department of Transportation
Bureau of Materials and Physical Research

State of Illinois
DEPARTMENT OF TRANSPORTATION
Division of Highways
Bureau of Materials and Physical Research

IMPLEMENTATION PACKAGE:

EMULSIFIED ASPHALT-AGGREGATE MIXTURES - MIX DESIGN AND DESIGN COEFFICIENTS

April 1981

CONTENTS

CONTENTS (cont'd.)

PART ONE

MIXTURE DESIGN

PART TWO

DESIGN COEFFICIENTS

EMULSIFIED ASPHALT-AGGREGATE MIXTURE DESIGN (EAM)

1. GENERAL

1.01 INTRODUCTION

This design method for cold-mix emulsified asphalt-aggregate paving mixtures currently in use by the Illinois Department of Transportation is based on research conducted at the University of Illinois using a modified Marshall method of mix design and a moisture durability test. The method and recommended test criteria are applicable to paving base course mixtures for low traffic volume pavements containing emulsified asphalt and dense-graded mineral aggregates with maximum sizes of one inch (25 mm) or less. This design is recommended for road mixes or plant mixes prepared at ambient temperatures.

1.02 OUTLINE OF METHOD

The design procedure involves the following major parts:

(1) Aggregate tests. Tests are conducted to determine aggregate properties and suitability for use in emulsified asphalt mixtures.

(2) Emulsified asphalt quality tests. Tests are conducted to determine emulsion properties and quality.

(3) Type and approximate amount of emulsion. A simplified procedure is used to estimate a trial residual asphalt content for a given aggregate. Using the trial asphalt content, coating tests are then conducted to determine the suitable type(s) of asphalt emulsion(s) and amount(s) of pre-mixing water required.

(4) Variation of residual asphalt content. Using the required pre-mixing water and optimum water content, mixtures are prepared at varying residual asphalt contents. The mixtures are then compacted into Marshall specimens and air cured for two days. The specimens are tested for bulk density, modified Marshall stability, and flow. Moisture susceptibility of the mixture is evaluated by subjecting a series of specimens to a special capillary water soak test for four days.

(5) Selection of optimum asphalt content. The optimum asphalt content is chosen as the percentage of emulsified asphalt at which the paving mixture best satisfies all of the design criteria.

1.03 OBJECTIVE

Provide an adequate amount of residual asphalt to economically stabilize granular materials to:

--- Give required strength or stability to withstand repeated load applications (compressive and flexural) without excessive permanent deformation or fatigue cracking.

--- Render the mixture sufficiently insensitive to moisture effects.

2. TESTING OF AGGREGATE

2.01 GENERAL

Aggregate properties are the determining factor in many of the choices made concerning the optimum mixture. Thorough testing of the aggregate therefore is necessary. A wide range of materials are suitable for use with emulsified asphalt including crushed stone, rock, gravel, sand, silty sand, sandy gravel, slag, reclaimed aggregate, ore tailings, or other inert materials.

Approximately 80 lb (36.3kg) of aggregate is required for the material tests. An additional 150 lb (68.1kg) of aggregate is required for each emulsion type and grade to be evaluated in the mixture design.

2.02 AGGREGATE TESTS

The following tests shall be performed on the aggregate as obtained from the pit/quarry:

(1) Sieve or screen analysis of fine and coarse aggregates:

Washed sieve	ASTM C 117 C 136	AASHTO T 11 T 27

(2) Specific gravity and absorption of coarse aggregate:

ASTM C 127 AASHTO T 85

(3) Specific gravity and absorption of fine aggregate:

ASTM C 128 AASHTO T 84

(4) Sand equivalent value of fine aggregate:

ASTM D 2419 AASHTO T 176

(5) Moisture-density relations of soils (optimum moisture):

AASHTO T 99

Additional Tests for Processed Aggregates:

(6) Soundness of aggregates by use of sodium sulphate or magnesium sulphate:

ASTM C 88 AASHTO T 104

(7) Abrasion of coarse aggregate by use of the Los Angeles abrasion machine:

ASTM C 131 AASHTO T 96

Tentative recommended guidelines for aggregate quality control criteria are shown in Table 1.

3. TESTING OF EMULSIFIED ASPHALT

Specifications for emulsified asphalts are given in the Illinois Department of Transportation's "Manual for Certification of Emulsified Asphalt Producers," dated January 1, 1980.

4. TRIAL RESIDUAL ASPHALT CONTENT

4.01 GENERAL

The first step is to establish a trial residual asphalt content. Based upon several emulsified asphalt mixture design parameters, an equation was derived that gives an approximate residual asphalt content. The information required to use this method is obtained from the washed sieve aggregate gradation.

4.02 CALCULATION OF TRIAL RESIDUAL ASPHALT CONTENT

The method for calculating the trial residual asphalt content is as follows:

$$R = 0.00138AB + 6.358 \log_{10}C - 4.655$$

TABLE 1. AGGREGATES FOR COLD-MIX
EMULSIFIED ASPHALT MIXTURES

Sieve Size	Gradation One Percent Passing	Gradation Two Percent Passing
1 1/2"	100	
1"	90-100	100
1/2"	60-90	65-95
No. 4	30-56	40-60
No. 16	10-40	15-45
No. 200	4-12	5-13
Sand Equivalent	30 Min.	30 Min.
Los Angeles Abrasion	45 Max.	45 Max.
Soundness Loss %	25 Max.	25 Max.

The above gradations may be modified by special provision to include the use of sand and silty sand mixtures. In no instance should any aggregate with a sand equivalency less than 30 be used.

where R = trial residual asphalt content by weight of dry aggregate, %
A = percentage of aggregate retained on No. 4 (4.75 mm) sieve
B = percentage of aggregate passing a No. 4 (4.75 mm) sieve and retained on the No. 200 (75 um) sieve)
C = percentage of aggregate passing the No. 200 (75 um) sieve

NOTE: Gradation based only on washed sieve gradations. R is rounded off to the nearest half percent to yield the trial residual asphalt content.

Example:

Retained on No. 4 (4.75 mm) sieve = 35 percent
Passing No. 4 (4.75 mm) and Retained on No. 200 (75 um) sieve = 57 percent
Passing No. 200 (75 um) sieve) = 8 percent
$R = 0.00138 \times 35.0 \times 57.0 + 6.358 \log_{10}(8.0) - 4.655 = 3.84$

Use R - 4.0 percent.

Trial residual asphalt content (R) = 4.0 percent by weight of dry aggregate. To obtain an emulsified asphalt content, it is necessary to divide the trial residual asphalt content (R) by the fraction of residual asphalt contained in the emulsion. The following is an example for a CSS-1 emulsion:

Trial Residual Asphalt Content = 4.0 percent

Residual Asphalt in CSS-1 Emulsion = 57 percent

$$\text{Trial Emulsion Content} = \frac{4.0}{.57} = 7.02 \text{ percent.}$$

5. COATING

5.01 GENERAL

Selection of emulsified asphalt type and grade for use on a particular project is based in part on the ability of the emulsion to adequately coat the job aggregate. Some factors which affect this selection are:

(1) Aggregate type.
(2) Aggregate gradation and characteristics of the fines.
(3) Anticipated water content of the aggregate.
(4) Availability of water at the construction site.

More than one emulsion type is often acceptable for a given aggregate, and the selection should be based on mixture properties determined by comparative mixture designs. Additional factors that cannot be evaluated at the time of design of the mixture, but which should be accounted for at the time of construction are:

(1) Anticipated weather at the time of construction.
(2) Type of mixing process.
(3) Construction equipment selected and field procedures used.

5.02 COATING TEST

Preliminary evaluation of each emulsion selected for mixture design is accomplished through a coating test. The trial residual asphalt content, as determined in Section 4.02, is combined with the job aggregate, and coating is visually estimated as a percentage of the total area. An emulsion's ability to coat an aggregate is usually sensitive to the pre-mix water content of the aggregate. This is especially true for aggregates containing a high percentage of material passing a No. 200 (75 um) sieve, where insufficient pre-mixing water results in balling of the asphalt with the fines and insufficient coating. For this reason, the coating test is performed at varying aggregate water contents. Emulsions which do not pass the coating test are not considered further. Detailed procedures for the coating test are listed below.

(1) Equipment

(a) Balance, 5,000g minimum capacity and accurate to within $\pm$ 0.5g.

(b) Laboratory mixing equipment, preferably mechanized and capable of producing intimate mixtures of the job aggregate, water and asphalt emulsion material. Hand mixing, if used, must be sufficiently thorough to uniformly disperse the water and emulsion throughout the aggregate.

(c) Hot plate or $230^{\circ} \pm 9^{\circ}F$ ($110^{\circ}C \pm 5^{\circ}C$) oven.

(d) Supply of round bottom mixing bowls (approximately 5 quart (4.7 litre) capacity).

(e) Supply of metal kitchen mixing spoons (approximately 10 in. (25.4cm)).

(f) A one-hundred millilitre glass graduate.

(g) Heavy paper plates, approximately 8 inches in diameter.

(2) Procedure

(a) Obtain representative samples of each emulsion considered for the project.

(b) Obtain representative samples of the job aggregate or aggregate blend.

(c) Prepare the aggregate by air drying. Any suitable means of drying which does not heat the aggregate in excess of 140°F (60°C) or cause degradation of the particles may be used. The aggregate should be stirred frequently to prevent crusting or formation of hard lumps.

(d) Determine the moisture content of a sample of the air-dried aggregate according to ASTM Test Method D 2216, "Laboratory Determination of Moisture Content of Soil," and record.

(e) Weigh out a sufficient number of batches of the air-dried job aggregate for trial mixes. The batch weight should be approximately 1,000g (oven dry basis).

(f) The percent of water to be added to the first batch is determined by subtracting the trial emulsion content (Section 4.02) from the Optimum Moisture Content (Section 2.02(5)). The water content for successive batches is varied in onehalf percent increments (on either side of the Optimum Moisture).

<u>NOTE</u>: Aggregate containing clay should be placed in a sealed container for a minimum of 15 hours prior to the addition of emulsion.

(g) Add the amount of emulsified asphalt (percent by weight of dry aggregate) as determined in Article 4.02. The emulsion should be added in a thin stream to minimize the tendency of the asphalt to ball up with the fine aggregate. If hand mixing is used, it should be sufficiently thorough to disperse the asphalt throughout the mixture.

(h) After the batch is thoroughly mixed, approximately one-half of the batch is deposited on a paper plate. The portion left in the mixing bowl is subjected to a rinse of tap water. The emulsion should not be completely removed from the aggregate by the rinse. The portion on the paper plate is reserved until all batches are mixed and then is used for the coating test rating.

NOTE: If the asphalt does not adhere to the aggregate, during rinsing, the emulsion should be adjusted by the manufacturer, the source and/or type emulsion should be changed, or the aggregate source changed and the procedure of the coating test repeated.

(i) Rate the appearance of the surface dry mixtures on the paper plates by visually estimating the total aggregate surface area that is coated with asphalt. For each pre-mix water content at mixing, record the estimate of the coating as a percentage of the total area. Aggregate coating in excess of 50 percent shall be considered acceptable. If the mixture does not attain 50 percent coating at any water content, the emulsion shall be rejected from further consideration. If the coating appears borderline, the mixture may be evaluated by the full mixture design procedure.

NOTE: It is important to recognize that 100 percent coating common to hot-mixed materials is desirable but not required. Sufficient asphalt to produce 100 percent coating may result in an excessively high asphalt content.

(j) For anionic emulsions, record the following water contents:

1. Minimum pre-mix water content to attain 50 percent coating.

2. Pre-mix water content to attain optimum coating.

3. Maximum pre-mix water content to attain 50 percent coating.

The range of minimum to maximum pre-mix water content to attain 50 percent coating shall be the acceptable range of mixing water contents for field construction. All subsequent mixing shall be done at the water content which produces optimum coating.

NOTE: Some combinations of aggregate and emulsion are not significantly affected by a variation of water content at mixing. In these cases, mixing may be allowed at or above the optimum water content as determined for compaction.

(k) Cationic emulsified asphalt mixtures generally exhibit increased coating as the pre-mix water content is incrementally increased. At some point, sufficient water is available for optimum dispersion of the asphalt and additional increments of water do not improve coating. This result shall be the minimum pre-mix water content required for mixing. All subsequent mixing in the design process shall be done at the minimum pre-mix water content.

6. PREPARATION OF SAMPLES

6.01 GENERAL

The mixture design procedure utilizes standard Marshall specimens in the evaluation of mixture properties. Triplicate specimens are prepared for both the stability and capillary moisture soak tests to insure reliability.

6.02 EQUIPMENT

The equipment required for the preparation of test specimens is as follows:

(1) Scoop, for batching aggregate.

(2) Thermometer, armored, glass or dial type with metal stem, +50°F (10°C) to + 150°F (65.5°C).

(3) Balance, 10kg capacity, sensitive to ± 1g, for weighing aggregate and mixtures.

(4) Balance, 2kg capacity, sensitive to ± 0.1g, for weighing compacted specimens and bulk density determination.

(5) Mixing spoon, large.

(6) Spatula, small and large.

(7) Mechanical mixer, capacity to handle 7000g.

(8) Compaction pedestal consisting of an 8 x 8 x 18 in. (200 x 200 x 460mm) wooden post capped with a 12 x 12 x 1 in. (305 x 305 x 25mm) steel plate. The wooden post should be oak, yellow pine or other wood having a dry weight of 42 to 48 lb/ft^3. The wooden post should be secured by four angle brackets to a solid concrete slab. The steel cap should be firmly fastened to the post.

The pedestal should be installed so that the post is plumb, the cap level, and the entire assembly is free from movement during compaction. This equipment is also used to conduct the Marshall method of hot-mix design.

(9) Compaction mold consisting of base plate, forming mold, and collar extension. The forming mold has an inside diameter of 4 in. (101.6mm) and height of approximately 3 in. (76mm); the base plate and collar extension are designed to be interchangeable with either end of the forming mold. This equipment is also used to conduct the Marshall method of hot-mix design.

(10) Water bath compaction mold, same as forming mold, with outside threads on both ends. These molds will be screwed onto threaded base plates (See Figure 1).

(11) Compaction hammer consisting of a flat circular tamping face 3-7/8 in. (98.4mm) diameter and equipped with a 10 lb (4.5kg) weight constructed to obtain a specified 18. (457mm) height of drop. This equipment is also used to conduct the Marshall method of hot-mix design.

(12) Mold holder, consisting of spring tension device designed to hold compaction mold in place on compaction pedestal. This equipment is also used to conduct the Marshall method of hot-mix design.

(13) Extrusion jack or Arbor press, for extruding compacted specimens from mold.

(14) Gloves, welders, for handling hot equipment; gloves, rubber, for removing specimens from oven.

(15) Marking crayons for identifying test specimens.

(16) Pans, metal, approximately 8 x 14 x 2 in. (200 x 355 x 50mm) for batching aggregates.

(17) Oven, forced draft, capable of maintaining a temperature of 200 $\pm$ 5°F (93.3 $\pm$ 2.8°C) for aerating mixtures; oven, forced draft, capable of maintaining a temperature of 230 $\pm$ 5°F (110 $\pm$ 2.8°C) for determining moisture contents.

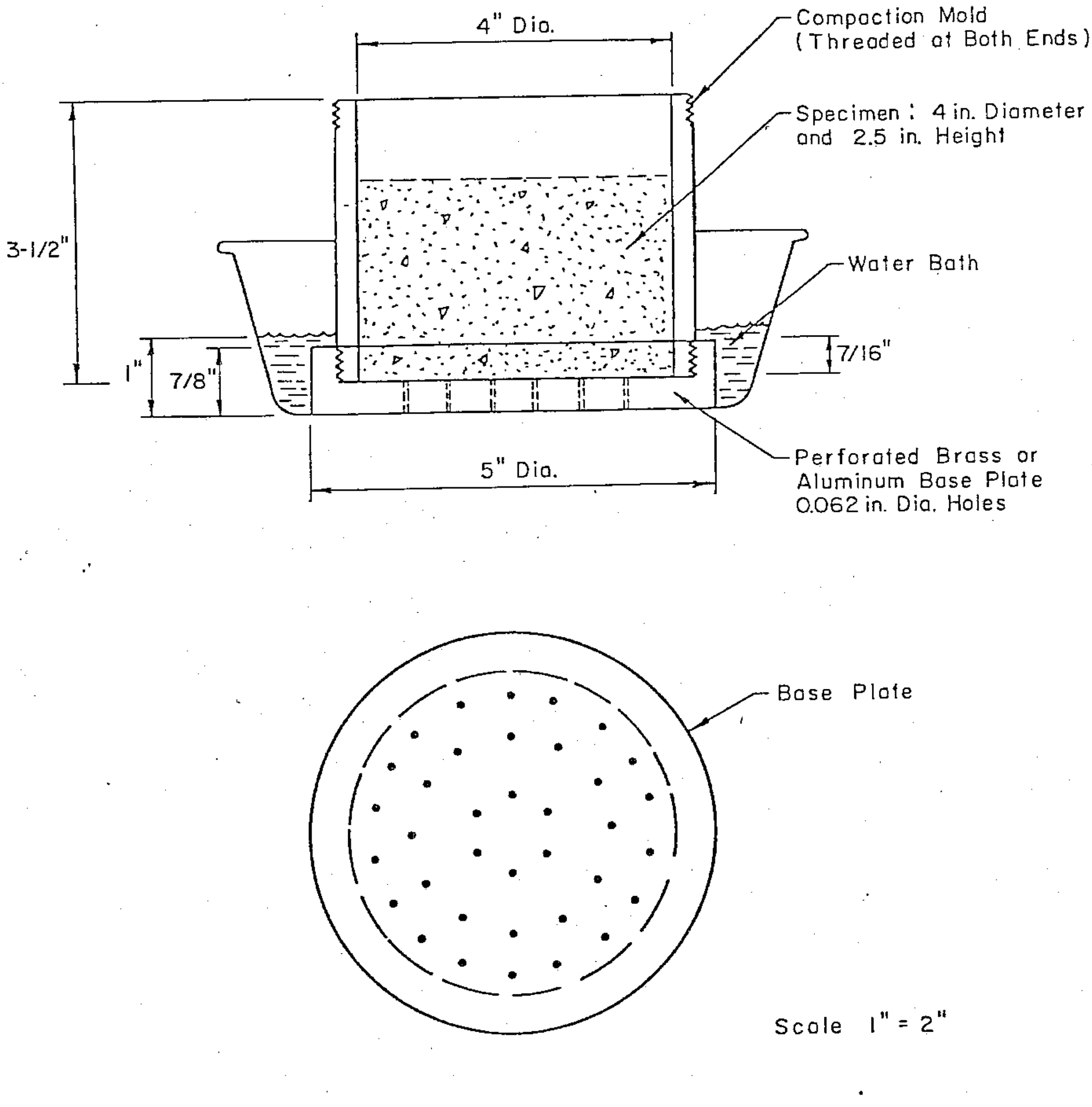


Figure 1. Emulsified Asphalt-Aggregate Mixture Soak Test Equipment.

6.03 PREPARATION OF TEST SPECIMEN

(1) Number of specimens. Prepare three specimens for each destructive test to be performed.

(2) Preparation of molds and hammer. Thoroughly clean the specimen mold assemblies and the face of the compaction hammer. Place a piece of filter paper toweling cut to size in the bottom of the mold before placing mixture in the mold.

(3) Preparation of aggregate. Each batch shall have a total aggregate weight of 3600g. Place the pans in a well ventilated area and determine the temperature of the aggregate. The temperature should be adjusted to $72 \pm 3^{o}F$ ($22.2 \pm 1.7^{o}C$) prior to mixing.

(4) Calculations. Three calculations are required for each combination of aggregate and asphalt: weight of aggregate, weight of emulsion, and the weight of mixing water. The following formulas are used for the calculations.

(a) Weight of air-dried aggregate = $\frac{a}{100 - b} \times 100$

(b) Weight of emulsion = $\frac{a \times c}{d}$

(c) Weight of mixing water = $a(f - b - \frac{e \times c}{d})\ 100$

where a = weight of dry aggregate
b = percent water content of air-dried aggregate
c = desired residual asphalt content, percent weight dry aggregate
d = percent residual asphalt in the emulsion
e = percent water in emulsion = 100 - d
f = percent mix water content at mixing (weight dry aggregate)

(5) Addition of pre-mixing water. Place the air dried aggregate in the mechanical mixer. Calculate the total amount of free water that needs to be added to achieve the optimum pre-mixing water as determined in the coating test (Section 5.02). Measure the volume of added water in a graduated cylinder. The temperature of the water shall be $72 \pm 3^{o}F$($22.2 \pm 1.7^{o}C$). Add the water in a slow stream

and mix for 2 $\pm$ .5 minutes or until the water is thoroughly dispersed throughout the aggregate. For aggregates containing clay the material shall be placed in a sealed container for a minimum of 15 hours. Weigh the emulsified asphalt container and record. Subtract the required weight of emulsion to determine the final weight of the container to produce the desired residual asphalt content. Add the emulsion to the moistened aggregate in a thin stream as the material is mixing. Reweigh the emulsified asphalt container periodically to ensure the required weight of emulsion is not exceeded. The mixing process may require 5 minutes. Excessive mixing tends to strip the asphalt from the aggregate and should be avoided.

(6) Compaction of specimens. For specimens to be tested in the modified Marshall stability test use standard Marshall forming molds. For specimens to be soaked in the water bath use specially threaded Marshall forming molds. Assemble the base plate, Marshall forming mold, and collar extension. Cover the base plate with a piece of filter paper cut to size and place 1200 $\pm$ 5g of mixture in the mold assembly. Spade the mixture with a small spatula 15 times around the perimeter and 10 times over the interior. Place a second piece of filter paper cut to size over the top of mixture. Repeat this process for the remaining mold assemblies.

Place the first mold assembly on the compaction pedestal in the mold holder and apply 75 blows with the compaction hammer. Remove the collar and base plate, reverse the mold and reassemble. Apply the same number of compaction blows to the face of the reversed specimen. Repeat the process for the remaining mold assemblies. Remove the collars, base plates, and filter paper from all specimens. Specimens are now ready for curing.

(7) Curing of Specimens. Specimens are cured at 72 $\pm$ 3.0^oF (22.2 $\pm$ 1.7^oC) in the forming mold for a specified curing period of 24 hours. The specimens must be set on their edge for equal ventilation on both sides. Remove the specimens from the mold approximately 2 hours prior to the intended testing time and warm to 72 $\pm$ 2^oF (22.2 $\pm$ 1.1^oC). A water bath should not be used unless the specimens are sealed in a plastic bag to prevent moisture absorption.

NOTE: Generally it is desirable to prepare a single trial specimen for each type of aggregate considered for the job prior to compacting the test specimens. Should the height of the extruded trial specimen fall outside the limits of 2.5 $\pm$ .25 in., the amount of mixture per specimen may be adjusted as follows:

Adjusted weight of aggregate per specimen =

$$\frac{2.5\ (\text{weight of aggregate used})}{(\text{specimen height (in.) obtained})}$$

or for International System of Units (SI):

Adjusted weight of aggregate =

$$\frac{63.5\ (\text{weight of aggregate used})}{(\text{specimen height (mm) obtained})}$$

7. VARIATION OF RESIDUAL ASPHALT CONTENT

7.01 GENERAL

In determining the optimum residual asphalt content for a particular aggregate and asphalt combination, a series of test specmens are prepared over a range of residual asphalt contents. Test mixtures are prepared in one percent increments of residual asphalt content with two increments on either side of the trial asphalt content determined in Section 4.02. If further definition of test results is required, increments farther away from the trial residual asphalt content are prepared.

7.02 EQUIPMENT

The equipment required for preparation of specimens is listed in Section 6.02.

7.03 PREPARATION OF SPECIMENS

Use the Procedure for Preparation of Specimens listed in Section 6.03. Additional instructions and clarifications presented below correspond to the appropriate Sections of 6.03.

(1) Number of specimens. Prepare three specimens for each residual asphalt content for the soaked stability test.

(2) Preparation of molds and hammer. No change.

(3) Preparation of aggregate. Use a total aggregate weight of 3.6kg.

(4) Calculations. No change.

(5) Addition of mixing water. As the residual asphalt content increases, the amount of water contributed by the emulsion increases. Thus, the amount of pre-mix water added will be reduced as the residual asphalt content is increased. Vary the residual asphalt content on successive batches to yield four one-percent increments (the trial residual asphalt content and one or two percent increments on either sides of the trial).

(6) Compaction of specimens. Use three specially threaded Marshall molds for specimen of each residual asphalt content.

(7) The specimens for the soaked stability test are cured at $72 \pm 3^{0}F$ for 24 hours in the threaded molds before testing as outlined in Section 8.05.

8. TEST PROCEDURE

8.01 GENERAL

To complete the mix design, the following tests and analyses are made from data obtained from the compacted specimens:

Bulk Specific Gravity.

Modified Marshall Stability and Flow of Dry Specimens at $72 \pm 2^{o}F$ ($22.2 \pm 1.1^{o}C$).

Soaked Stability and Flow at $72 \pm 2^{o}F$ ($22.2 \pm 1.1^{o}C$) after 4-day soak test.

Density and Voids Analysis.

Moisture Absorption during soak test.

Table 2 is a detailed data sheet that can be used to record pertinent data and perform calculations.

8.02 EQUIPMENT

The equipment required for the testing of the 4 in. (102mm) diameter x 2 1/2-in. (64mm) height specimens is as follows:

(1) Marshall Testing Machine. An electrically powered (110-volt) testing device. It is designed to apply loads to test specimens through semicircular testing heads at a constant rate of strain of 2 in. (50.8mm) per minute. It is equipped with a calibrated proving ring for determining the applied testing load, a Marshall stability testing head for use in testing the specimen and a Marshall flow meter for determining the amount of strain at the maximum load for the test. A universal testing machine equipped with suitable load and deformation indicating devices may be used instead of the Marshall testing frame.

(2) Water Bath. At least 24 in. x 36 in. x 6 in. (610mm x 915mm x 155mm) and thermostatically controlled at 72 $\pm$ 2^{o}F (22.2 $\pm$ 1.1^{o}C).

(3) Pans, either 9 x 9 in. (229 x 229mm) or 10 in. (254mm) in diameter and 1 in. (25.4mm) deep capable of containing failed specimens for moisture content determination.

(4) Balances, 1500g capacity, equipped for bulk density determination.

(5) Towel, cloth for drying samples during bulk density determination.

(6) Ruler, 6 in. (150mm), calibrated in 1/16 in. (1mm).

8.03 BULK SPECIFIC GRAVITY DETERMINATION

The method used for determination is ASTM D 2726, "Test for Bulk Specific Gravity of Compacted Bituminous Mixture Using Saturated Surface Dry Specimens."

TABLE 2. EMULSIFIED ASPHALT MIXTURE DATA SHEET
(Use for specimens containing a single residual asphalt content)

ASPHALT		AGGREGATE	
Type & Grade	HFE 300	Source Id.	R.P.C.
Asphalt in Emulsion	57 %	Type	CA6
Asphalt Spec. Gra. (B)	1.00	Bulk Spec. Gra. (C)	2.58
Residual Asphalt in Mixture (A)	4 %		

MIXING AND COMPACTION		TESTING	
Total Mix Water	4 %	Dry Spec. Test Date	9/5/80
Added Mix Water	71 g	Rotate Soak Spec. Date	9/7/80
Water at Comp.	4 %	Soak Spec. Test Date	9/9/80
Compaction Date	9/3/80		

COMPACTED SPECIMEN DATA	Dry			Soaked		
	1	2	3	4	5	6
Bulk Density						
Weight in Air (D)	1150.0	1152.1	1173.0			
Weight in Water (E)	641.0	654.0	664.0			
Weight SSD (F)	1152.1	1161.0	1185.1			
BSG - compacted mix (G)	2.25	2.27	2.25			
Dry BSG - compacted mix	223	224	225			
Thickness	2.5	2.5	2.5			
Stability						
Dial	116	123	129	110	105	124
Load	1045	1105	1165	1009	960	1110
Adjusted Stability (L)	1045	1105	1165	1009	960	1110
Flow	17	13	12	19	13	15
Moisture Content						
Weight of failed specimen (H)	1305.2	1316.1	1335.0	1237.8	1237.8	1236.4
Weight of oven-dry specimen (I)	1284.1	1291.0	1320.2	1198.2	1195.2	1195.4
Tare (J)	161	159	155	154	157	159
Moisture content (K)	0.78	1.38	0.22	3.64	3.90	3.78
Moisture absorbed				2.38		
Maximum Total Voids - %	8.12	7.70	730			

MIX DESIGN CALCULATIONS
FOR USE WITH TABLE 2

$$G = \frac{D}{F - E}$$

$$\text{Dry BSG} = \frac{G}{1 + K/100}$$

$$\text{Moisture content } K = \frac{(H - I) - (F - D)}{I - J} \times \frac{1}{1 + A/100}$$

$$\text{Moisture absorbed} = \frac{K1 + K2 + K3}{3} - \frac{K4 + K5 + K6}{3}$$

$$\text{Maximum total voids} = \frac{\frac{A/100 + 1 + K/100}{G} - \frac{1}{C} - \frac{A/100}{B}}{\frac{A/100 + 1 + K/100}{G}} \times 100$$

$$\text{Stability loss} = \frac{L1 + L2 + L3 - L4 - L5 - L6}{L1 + L2 + L3} \times 100$$

NOTE: Letters A through L refer to identical letters in Parentheses in Table 2.

8.04 MODIFIED STABILITY AND FLOW TESTS

After determining the bulk specific gravity of the dry extruded specimens, test for stability and flow as follows:

(1) Thoroughly clean the guide rods and inside surfaces of the test heads prior to making the test, and lubricate the guide rods so that the upper test head slides freely over them. The testing head temperature is maintained between 70 and 74°F (21.1 and 23°C) using a water bath when required. Check the load measuring device for zero "adjustment."

(2) Place one of the three specimens into position on the lower testing head and center complete assembly in the loading device. Place the flow meter over marked guide rod.

(3) Apply testing load to specimen at constant rate of deformation of 2 in. (50.8mm) per minute until failure is obtained. The total number of pounds (newtons) required to produce failure of the specimen at $72^{o} \pm 2^{o}$F ($22.2^{o} \pm 1.1^{o}$C) shall be recorded as its modified Marshall stability.

(4) While the stability test is in progress, hold the flow meter firmly in position over the guide rod and remove it the instant the maximum load starts to decrease. Note and record the indicated flow value in units of 0.01 in. (0.25mm).

(5) Place the failed specimens in preweighed pans taking care to make sure all of the failed specimen is put into the pan. The specimens are broken up, weighed, weights recorded in the column headed by "Weight of Failed Specimen," and put in an oven at $200^{o} \pm 10^{o}$F ($93^{o} \pm 6^{o}$C). The specimens are removed after 24 hours, reweighed, and the weights recorded under the heading "Weight of Oven Dried Specimen". The weight of the water is corrected by subtracting the weight of water absorbed during bulk specific gravity determination. The weight of the water absorbed can be determined by subtracting the weight of the dry specimens from the weight of the SSD specimen. From the data obtained above, a water content at testing is determined.

8.05 SOAKED STABILITY AND FLOW TESTS

After testing the extruded specimens, the remaining three samples are left to be placed in the capillary soak test.

(1) Immediately after the testing of the extruded samples, the specimens in the specially threaded molds are brought flush to the end of the mold by use of the extrusion jack.

(2) Brass or aluminum base plates are then screwed on the flush ends of the molds. The assemblies are then placed with the flush ends down in a water bath. The depth of water is maintained at 1 in. and at a temperature of $72^{o} \pm 3.0^{o}$F ($22.2^{o} \pm 1.7^{o}$C). The top of the mold is covered to prevent evaportation of moisture.

(3) After 48 hours the assemblies are removed from the water bath. The base plates are removed and the specimens are brought flush with the opposite end of the mold. The base plates are again threaded on the flush end, the assemblies are placed with the flush ends down in the water bath, and the top is again covered.

(4) After 48 hours, the specimens are removed and extruded from the specially threaded molds.

(5) The specimens are then tested in modified Marshall stability and moisture content determination as outlined in Sections 8.03 and 8.04.

8.06 DENSITY AND VOIDS ANALYSIS

A density and voids analysis is conducted as follows:

(1) Determine each unit weight by multiplying the bulk specific gravity by 62.4 (unit weight in kg/m^3 multiplied by 1000).

(2) After determining water content at testing, aggregate bulk density, asphalt specific gravity, and mix bulk density, voids can be calculated by the following equation.

$$V = 100 - Gmbw\left(\frac{Pb}{Gb} + \frac{Pa}{Gsb}\right)$$

where V = voids (air plus moisture)

Pb = Residual asphalt in percent by weight of dry aggregate.

Gmbw = Bulk specific gravity of specimen.

GSB = Bulk specific gravity of the aggregate.

Gb = Specific gravity of the residual asphalt.

Pa = Aggregate in percent. (100 - Pb)

9. INTERPRETATION OF TEST DATA

9.01 PREPARATION OF DATA

The stability, flow, voids, bulk density, and moisture content data are prepared as follows:

(1) Measured stability values for specimens that depart from the standard 2-1/2 in. (63.5mm) thickness shall be converted to an equivalent 2-1/2 in. (63.5mm) value by means of a conversion factor. Applicable correlation ratios to convert the measured stability values are set forth in Table 3. Note that the conversion may be made on the basis of either measured thickness or measured volume.

(2) Average the flow values and the converted stability values for all specimens of a given asphalt content. Values that are obviously in error shall not be included in the average.

(3) Prepare a separate plot for the following factors as illustrated in Figure 2.

(a) Dry and soaked stability vs. residual asphalt content.

(b) Dry bulk density vs. residual asphalt content.

(c) Percent total voids vs. residual asphalt content.

(d) Percent moisture absorbed vs. residual asphalt content.

(e) Percent stability loss vs. residual asphalt content calculated by $\frac{\text{Dry Stab.-Soaked Stab.}}{\text{Dry-Stab.}} \times 100$

In each plot, connect the data with a smooth curve that provides the best fit for all values.

9.02 TRENDS AND RELATIONS OF TEST DATA

The test property curves as previously plotted have been found to vary considerably between aggregate types and gradations, but typical curves are shown in Figure 2.

General trends are described as follows:

(1) Soaked stability generally will show a peak at a particular residual asphalt content while dry stability will generally show a continually decreasing curve with increasing residual asphalt content (Figure 2(a)).

(2) Percent loss of stability generally decreases as residual asphalt content increases (Figure 2(b)).

(3) Dry bulk density usually peaks at a particular residual asphalt content (Figure 2(c)).

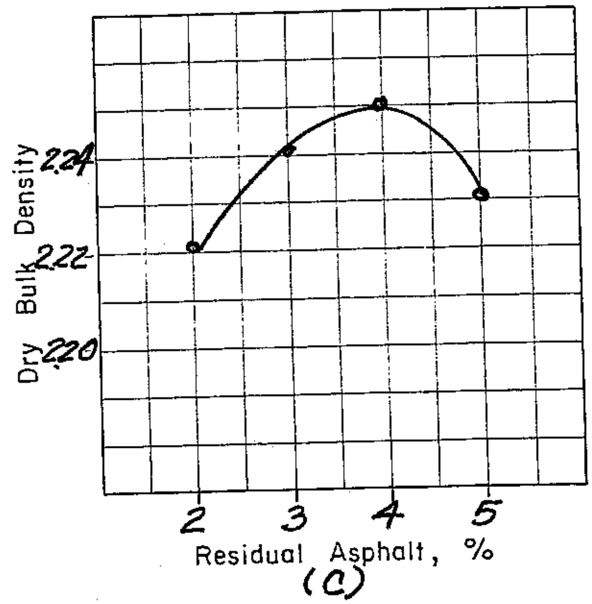
TABLE 3. STABILITY CORRELATION RATIOS

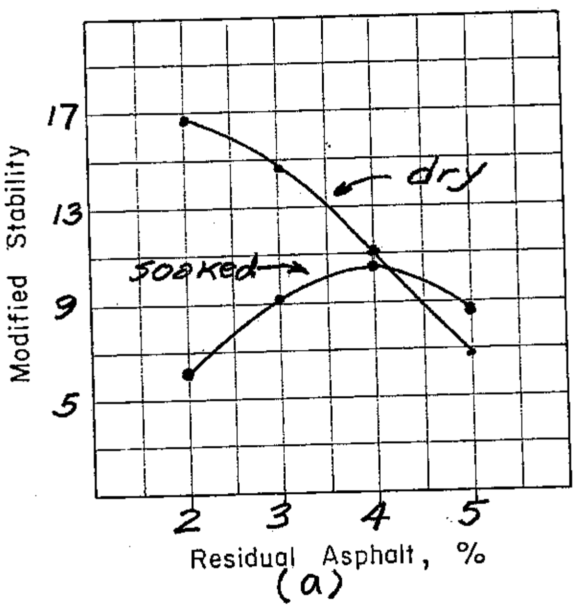
Volume of Specimen, cm^3	Approximate Thickness of Specimen (4" Dia.) in.	mm	Correlation Ration for Corrected Stability
200 to 213	1	25.4	5.56
214 to 225	1-1/16	27.0	5.00
226 to 237	1-1/8	28.6	4.55
238 to 250	1-3/16	30.2	4.17
251 to 264	1-1/4	31.8	3.85
265 to 276	1-5/16	33.3	3.57
277 to 289	1-3/8	34.9	3.33
290 to 301	1-7/16	36.5	3.03
302 to 316	1-1/2	38.1	2.78
317 to 328	1-9/16	39.7	2.50
329 to 340	1-5/8	41.3	2.27
341 to 353	1-11/16	42.9	2.08
354 to 367	1-3/4	44.4	1.92
368 to 379	1-13/16	46.0	1.79
380 to 392	1-7/8	47.6	1.67
393 to 405	1-15/16	49.2	1.56
406 to 420	2	50.8	1.47
421 to 431	2-1/16	52.4	1.39
432 to 443	2-1/8	54.0	1.32
444 to 456	2-3/16	55.6	1.25
457 to 470	2-1/4	57.2	1.19
471 to 482	2-5/16	58.7	1.14
483 to 495	2-3/8	60.3	1.09
496 to 508	2-7/16	61.9	1.04
509 to 522	2-1/2	63.5	1.00
523 to 535	2-9/16	64.0	0.96
536 to 546	2-5/8	65.1	0.93
547 to 559	2-11/16	66.7	0.89
560 to 573	2-3/4	68.3	0.86
574 to 585	2-13/16	71.4	0.83
586 to 598	2-7/8	73.0	0.81
599 to 610	2-15/16	74.6	0.78
611 to 626	3	76.2	0.76

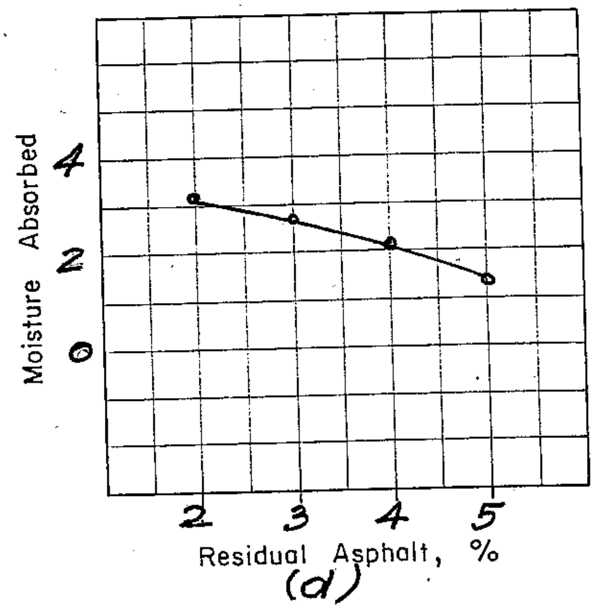
DESIGN TESTS
FOR
EMULSIFIED ASPHALT
MIXTURES

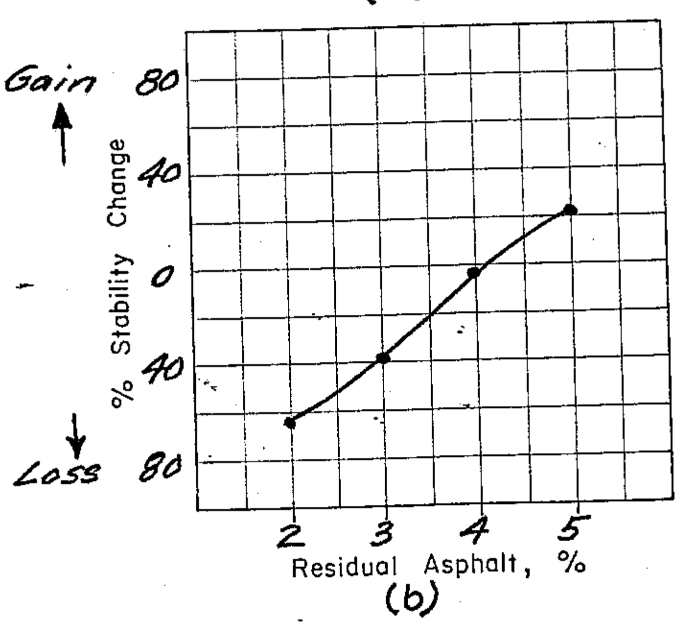
Design No. 1

Date 9/9/80









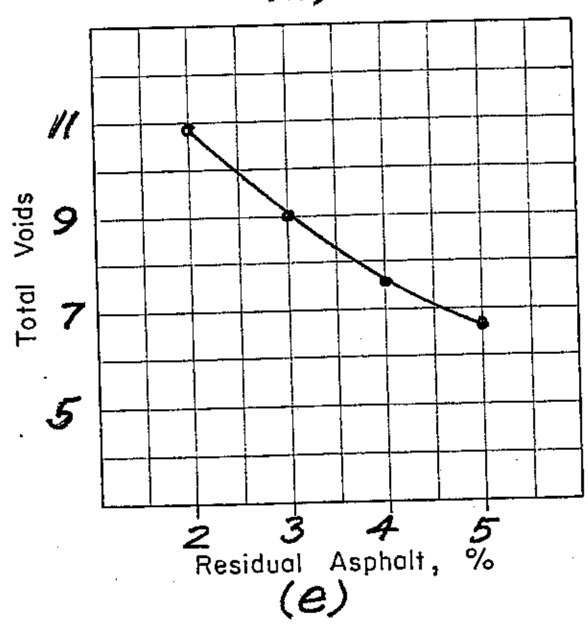


Figure 2.

(4) Percent moisture absorbed during the soak test decreases as residual asphalt content increases (Figure 2(d)).

(5) Percent total voids (air plus moisture) decreases as residual asphalt content increases (Figure 2(e)).

9.03 DETERMINATION OF OPTIMUM ASPHALT CONTENT

(1) The mixture must provide adequate stability when tested in a "soaked" condition to insure adequate support of traffic loads during wet seasons.

(2) The percent loss of stability of the mixture when tested "soaked" as opposed to "dry" should not be excessive. A high loss is indicative of the mixture having high moisture susceptibility and may cause disintegration during wet seasons.

(3) The total voids within the mixture should be within a specified range to prevent either excessive permanent deformation and moisture absorption (for a high void content), or bleeding of the residual asphalt from the mixture (for a low void content).

(4) Moisture absorption into the mixture should not be excessive to minimize the potential of stripping or weakening the bond between residual asphalt and aggregate.

(5) Residual asphalt should provide adequate coating of the aggregate and should be resistant to stripping or abrasion.

The optimum residual asphalt content for the paving mixture is determined from the data obtained as presented. The optimum residual asphalt content is chosen that provides maximum soaked stability, but is adjusted either up or down depending on moisture absorption, percent loss of stability, total voids, and coating of aggregates. Design criteria for each of these values is given in Table 4. If the residual asphalt content at the peak of the soaked stability curve provides for adequate moisture absorption, percent loss of stability, total voids, and aggregate coating, it is selected as the optimum asphalt content. This value must meet minimum stability requirements, however, as given in Table 4, or the mix is rejected. If one or more criteria cannot be met, the mix should be considered inadequate.

TABLE 4. EMULSIFIED ASPHALT-AGGREGATE MIXTURE DESIGN CRITERIA

Test Property	Minimum	Maximum
Soaked Stability, lb at 72°F (22.2°C) Paving Mixtures	500	-
Percent Total Voids Compacted Mix (does not apply to sand mixes)	2	8
Percent Stability Loss After 4 days soak at 72°F (22.2°C)	-	50
Percent Absorbed Moisture After 4 day soak at 72°F (22.2°C)	-	4
Aggregate Coating (Percent)	50	

The moisture content of the aggregate at mixing may have a significant effect on the above criteria for emulsified asphalt aggregate mixtures. While there is a fairly broad range of moisture which may be acceptable, it is generally desirable to use a minimum of water. This minimum amount of moisture is determined by the coating of the aggregate by the residual asphalt. The optimum moisture content at mixing, therefore, needs to be determined and then controlled to help achieve the desired criteria previously listed.

10. EXAMPLE EMULSIFIED ASPHALT-AGGREGATE MIXTURE DESIGN

10.01. MATERIALS

A crushed limestone aggregate and HFE-300 emulsified asphalt have been proposed for a project. Standard tests were conducted on the aggregate and emulsion which indicated both are within specifications. The optimum moisture content is 7.0 percent.

10.02. TRIAL RESIDUAL ASPHALT CONTENT

The washed aggregate gradation shows the following:

Retained No. 4 = 55 percent (A)
Passing No. 4 and retained on No. 200 = 37 percent (B)
Passing No. 200 = 8 percent (C)

The trial residual asphalt content is computed as follows:

$$R = 0.00138AB + 6.358 \log_{10}C - 4.655$$

$$= 0.00138 \times 55 \times 37 + 6.358 \log_{10} (8) - 4.655$$

$$= 3.90$$

<u>Use 4 percent</u>

10.03. COATING

Coating tests were conducted using the trial residual asphalt content and a range of mixing water contents (2-7 percent). Results showed the following:

Mixing Water Content	Estimated Coating Percent
2	90
3	85
4*	80
5	65
6	45

*Initial trial - 7.0% optimum - 3.0% water in emulsion

Thus, a mixing water content up to 6 percent for this specific emulsion and aggregate will provide adequate coating.

10.04. VARYING RESIDUAL ASPHALT CONTENT

Specimens were compacted at varying residual asphalt contents ranging over 2, 3, 4, and 5 percent (six specimens at each content). The specimens were dry cured 3 days. Three specimens from each asphalt content were tested in modified Marshall stability, bulk density, and water content. The other samples were placed in the moisture soak test for 4 days and then tested for modified Marshall stability and moisture content. Results from the modified Marshall stability test are shown in Figure 3. A peak soaked stability occurs at about 4 percent.

10.05. DENSITY AND VOIDS ANALYSIS

$$V = 100 - Gmbw \left(\frac{Pb}{Gb} + \frac{Pa}{Gsb} \right)$$

assuming: (from Table 2, page 16)

Pb = 4 percent residual asphalt

$Gmbw$ = 2.24 Bulk specific gravity of specimen

Gsb = 2.58 Bulk specific gravity of the aggregate

Gb = 1.0 Specific gravity of the asphalt

Pa = 96 percent aggregate

$$V = 100 - 2.24 \left(\frac{4}{1} + \frac{96}{2.58} \right)$$

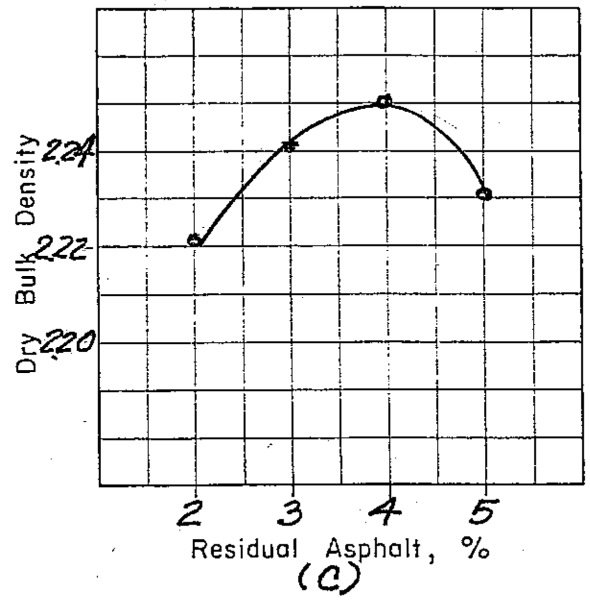
$$V = 100 - 92.4$$

$$V = 7.6 \text{ percent voids}$$

DESIGN TESTS
FOR
EMULSIFIED ASPHALT
MIXTURES

Design No. 1

Date 9/9/80



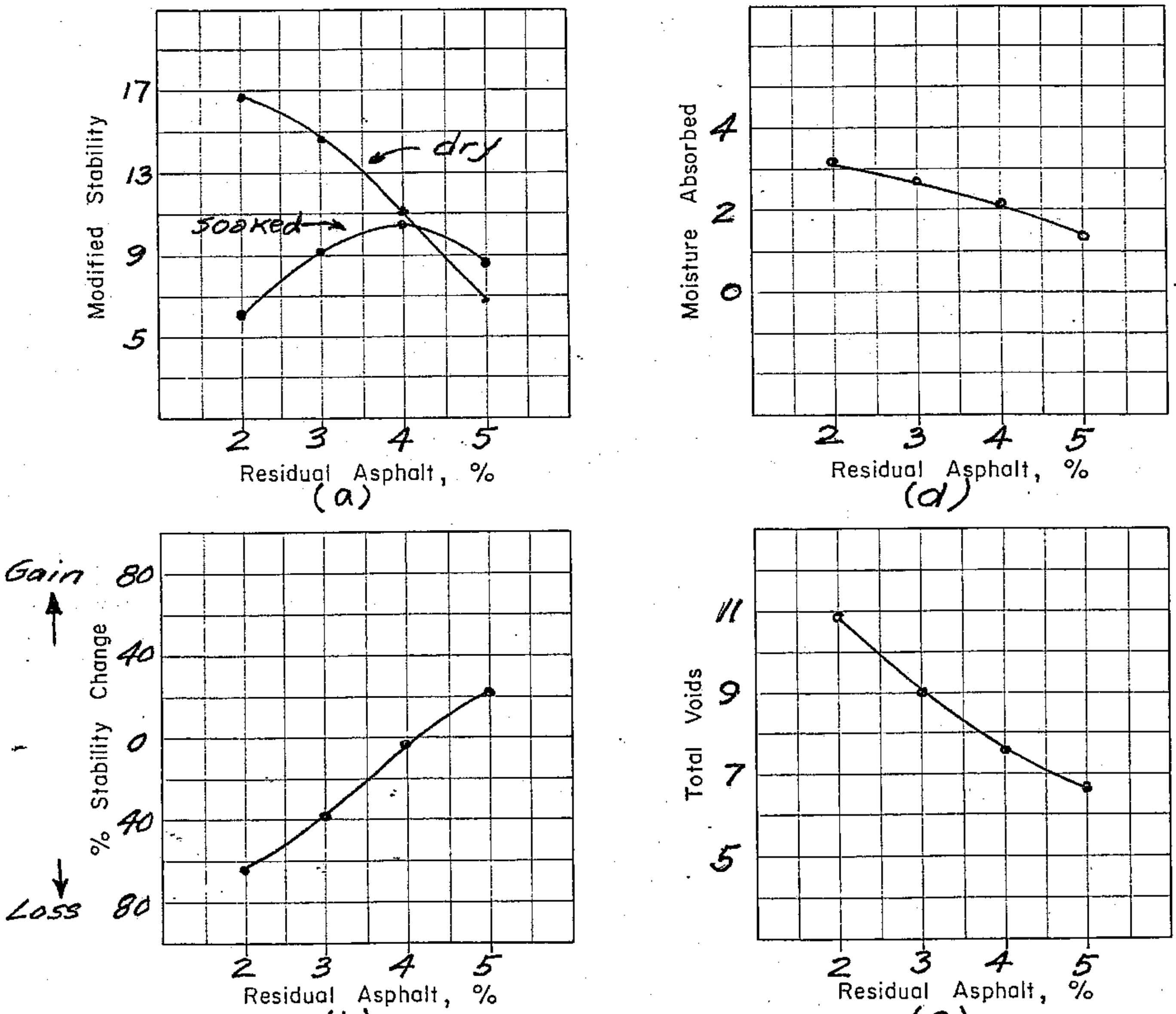


Figure 3.

10.06. SELECTION OF OPTIMUM RESIDUAL ASPHALT CONTENT

The residual asphalt content at peak soaked stability is 4.0 percent. The following values of other parameters are obtained, from the graphs for this content as shown in Figure 3.

Mix Parameter	Value at 4 Percent Residual Asphalt	Limiting Criteria
Percent Stability Loss	5	50 max
Total Voids	7.6	2-8
Percent Moisture Absorption	2.2	4 max
Soaked Modified Marshall stability, lbs.	1050	500 min

Therefore, all of the criteria are achieved at a residual asphalt content of 4 percent.

The following mixture design and construction recommendations are obtained:

1. Residual asphalt content = 4.0 percent by weight of dry aggregate.

2. Asphalt emulsion content (for an asphalt residual of 57 percent) = $\frac{4.0}{0.57}$

   = 7.0 percent by wt. of dry aggregate or approximately 14.6 gal/ton dry aggregate.

3. Mixing water content

   = optimum moisture content-moisture in emulsion

   = 7.0-3.0

   = 4.0%

   Use 3-5% by weight of dry aggregate.

Examples of the suggested format for reporting the completed mix design are presented in Figures 3 through 8.

EMULSIFIED ASPHALT MIXTURE DATA SHEET
(Use for specimens containing a single residual asphalt content).

ASPHALT		AGGREGATE	
Type & Grade	HFE 300	Source Id.	R.P.C.
Asphalt in Emulsion	57 %	Type	CA6
Asphalt Spec. Gra. (B)	1.00	Bulk Spec. Gra. (C)	2.58
Residual Asphalt in Mixture (A)	4 %		
MIXING AND COMPACTION		**TESTING**	
Total Mix Water	4 %	Dry Spec. Test Date	9/5/80
Added Mix Water	71 g	Rotate Soak Spec. Date	9/7/80
Water at Comp.	4 %	Soak Spec. Test Date	9/9/80
Compaction Date	9/3/80		

COMPACTED SPECIMEN DATA	Dry			Soaked		
	1	2	3	4	5	6
Bulk Density						
Weight in Air (D)	1150.0	1152.1	1173.0			
Weight in Water (E)	641.0	654.0	664.0			
Weight SSD (F)	1152.1	1161.0	1185.1			
BSG - compacted mix (G)	2.25	2.27	2.25			
Dry BSG - compacted mix	2.23	2.24	2.25			
Thickness	2.5	2.5	2.5			
Stability						
Dial	116	123	129	110	105	124
Load	1045	1105	1165	1009	960	1110
Adjusted Stability (L)	1045	1105	1165	1009	960	1110
Flow	17	13	12	19	13	15
Moisture Content						
Weight of failed specimen (H)	1305.2	1316.1	1335.0	1237.8	1237.8	1236.4
Weight of oven-dry specimen (I)	1284.1	1291.0	1320.2	1188.2	1195.2	1195.4
Tare (J)	161	159	155	154.2	156.6	159.1
Moisture content (K)	0.78	1.38	0.22	3.64	3.90	3.78
Moisture absorbed				2.38		
Maximum Total Voids - %	8.12	7.70	7.30			

Figure 4.

EMULSIFIED ASPHALT
MIXTURE DESIGN

TO:

FROM: R. Francis G , R. Francis Co.

DATE: 9/10/80

Contract No.: 12871

County: Mc Dough

Route: Fast 1

Section: 123 BS

District: 10

Project: none

Manufacturer: R. Francis Co.

Mixture Design Number: 01

We are attaching a copy of our test results on samples representing the ingredients proposed for use in the manufacture of the Emulsified Asphalt mixture. These data include the tests for the properties of the ingredients as well as laboratory tests on samples prepared from these materials.

Attachments

Figure 5.

EMULSIFIED ASPHALT MIXTURE DESIGN

NUMBER 01

DATE 9/9/80

Mix Producer R. Francis Co.

Asphalt Source & Grade Refined Pet Co. HFE300

Aggregate Source & Grade Unified St. Co. CA6

RECOMMENDED MIXING FORMULA:

Sieve Size	
1-1/2 inch	100
1 inch	95
1/2 inch	84
No. 4	44
No. 16	13
No. 200	5.7
Percent emulsion	7.0

Figure 6.

EMULSIFIED ASPHALT
DESIGN MIXING FORMULA PASSING

DESIGN NO.: 01

RECOMMENDED MIXING FORMULA:

From the data we recommend that these ingredient materials be proportioned to produce a mixture having the following approximate composition:

	Percent	Specification
Passing 1½ inch sieve, %	100	100
Passing 1 inch sieve, %	95.1	90-100
Passing inch sieve, %		
Passing ½ inch sieve, %	84.2	60-90
Passing No. 4 sieve, %	43.9	30-56
Passing No. sieve, %		
Passing No. 16 sieve, %	13.2	10-40
Passing No. sieve, %		
Passing No. 200 sieve, %	5.7	4-10
*Bitumen, % by wt. of dry agg.	7.0 (4.0 residual)	

The gradation given above is that which resulted from the combination of the ingredient materials submitted to the laboratory and is not necessarily the optimum gradation.

*A slight adjustment in the asphalt may be necessary after the job starts.

	Percent
Recommended Moisture for Mixing*	4
Recommended Moisture for Compaction*	4
Percent of Residual Asphalt in Emulsion	57

Mix Parameters	Value at 4 Percent E.A.	Limiting Critieria
Percent Stability Loss	5	50 max.
Total Voids	7.6	2-8
Percent Moisture Absorption	2.2	4 max.
Soaked Mod. Stability (72° F.)	1050	500 min.
Percent Aggregate Coating	80	50 min.

*by weight of dry aggregate

Figure 7.

EMULSIFIED ASPHALT DESIGN

Contractor: R. Francis Co. Route: FAST 1

Section: 1, 2, 3 BS. Project: County: W.C. Mc

Type of Mixture: Date: 9/9/80

Sources of the ingredient materials: Contract No.:

Type of Material	Source	Sp. G.		% Absorption
Gravel				
CA6 Stone	Unified Stone Co.	2.73	2.58	2.0
Coarse Sand				
Fine Sand				
Mineral Filler				
Emulsion HFE300	Refined Petroleum Co.	1.00		

MATERIALS	0/0	GRADATION - SIEVE SIZES 1½"	1"	½"		No.4		No.16		200	AC
CA GRAVEL											
CA 6 STONE		100	95.1	84.2		43.9		13.2		5.7	
COARSE SAND											
FINE SAND											
MINERAL FILLER											
CALCULATED MIX											
SPECIFICATION		100	90/100	60/90		30/56		10/40		4/12	

DESIGN TESTS

MIX NO.	RES. ASPT.	MODIFIED STABILITY (72^0 F.)	SOAKED STABILITY (96 Hrs.)	% STAB. LOSS	% MOISTURE ABSORBED	BULK SP. GR.	PERCENT VOIDS	MODIFIED FLOW
1a.	5.0	680	830	+22	1.4	2.23	6.6	15.6
b.	4.0	1105	1050	-5	2.2	2.25	7.6	14.0
c.	3.0	1470	910	-38	2.7	2.24	9.0	11.8
d.	2.0	1680	600	-65	3.1	2.22	10.9	9.7

Figure 8.

DESIGN COEFFICIENTS FOR EMULSIFIED ASPHALT-AGGREGATE PAVING MIXTURES

INTRODUCTION

The findings of research project IHR-505, Structural Evaluation of Asphalt Aggregate Cold Mixes, conducted by the University of Illinois, in cooperation with the Illinois Department of Transportation and the Federal Highway Administration, indicated that emulsified asphalt-aggregate paving mixtures (EAM) can be used effectively and economically as quality highway construction materials.

One phase of the IHR-505 effort was specifically directed toward developing a methodology based on structural concepts and techniques to relate physical test properties to structural coefficient. The following presents the salient information from this effort necessary to implement this base course material stabilization technique in the Illinois flexible pavement structural design procedure.

STRENGTH COEFFICIENT

Since emulsified asphalt-aggregate base courses were not used on the AASHO Road Test Project, no reference point has been established from which coefficient values can be directly correlated with strength characteristics for use in pavement structural design. The assignment of coefficient values, therefore, must be made by indirect procedures.

The IHR-505 work recommends that either a modified Marshall stability and/or a resilient modulus test be used as a meaningful measure of the strength required to withstand repeated load applications and mixture insensitivity to moisture. The researchers further found that estimates of coefficient values could be made by correlating mixture structural properties (modified Marshall stability and/or resilient modulus) with performance. The ensuing correlations were then used to establish relationships between structural properties of an EAM base and structural coefficient (a_2) as used in the Illinois design procedure.

Obviously, the relationship developed for relating modified Marshall stability to structural coefficient value has the most significance in Illinois due to greater familiarity with the Marshall design procedure and equipment availability. The generalized relationship developed is shown in Figure 9. It indicates that the structural coefficient (a_2) for EAM is believed to fall within the bounds of non-stabilized granular materials ($a_2 = 0.11$) and high-quality hot-mix asphalt-stabilized materials ($a_2 = 0.33$). While subject to further verification, this relationship is recommended for use. The following procedure is to be used in establishing the a_2 coefficient value for EAM base course.

Base Course Coefficient, a_2: The structural coefficient for EAM base course used in flexible pavements will be determined on the basis of the relationship shown in Figure 9 and the results of the laboratory mix design modified Marshall stability test results (outlined in Part One - Mix Design). The following two steps are required:

(1) Convert the laboratory mix design (soaked and dry) modified Marshall stability information to a "design" modified Marshall stability value for use in Figure 9.

(2) Convert the above determined "design" modified Marshall stability value to a structural coefficient value (a_2) using the relationship shown in Figure 9.

Each of the steps is discussed in the ensuing paragraphs.

In broad terms, the conversion of laboratory mix design soaked and dry modified Marshall information to a design modified Marshall stability value involves the following general relationship:

$$MS_{Design} = MS_f \frac{(MS_m)}{(MS_d)}$$

where

MS_{Design} = Design modified Marshall stability

MS_f = final modified Marshall stability
$= MS_d \times CF$

MS_d = dry modified Marshall stability

CF = curing factor

MS_m = soaked modified Marshall stability

COEFFICIENTS FOR EMULSIFIED ASPHALT - AGGREGATE BASE COURSE MIXTURES

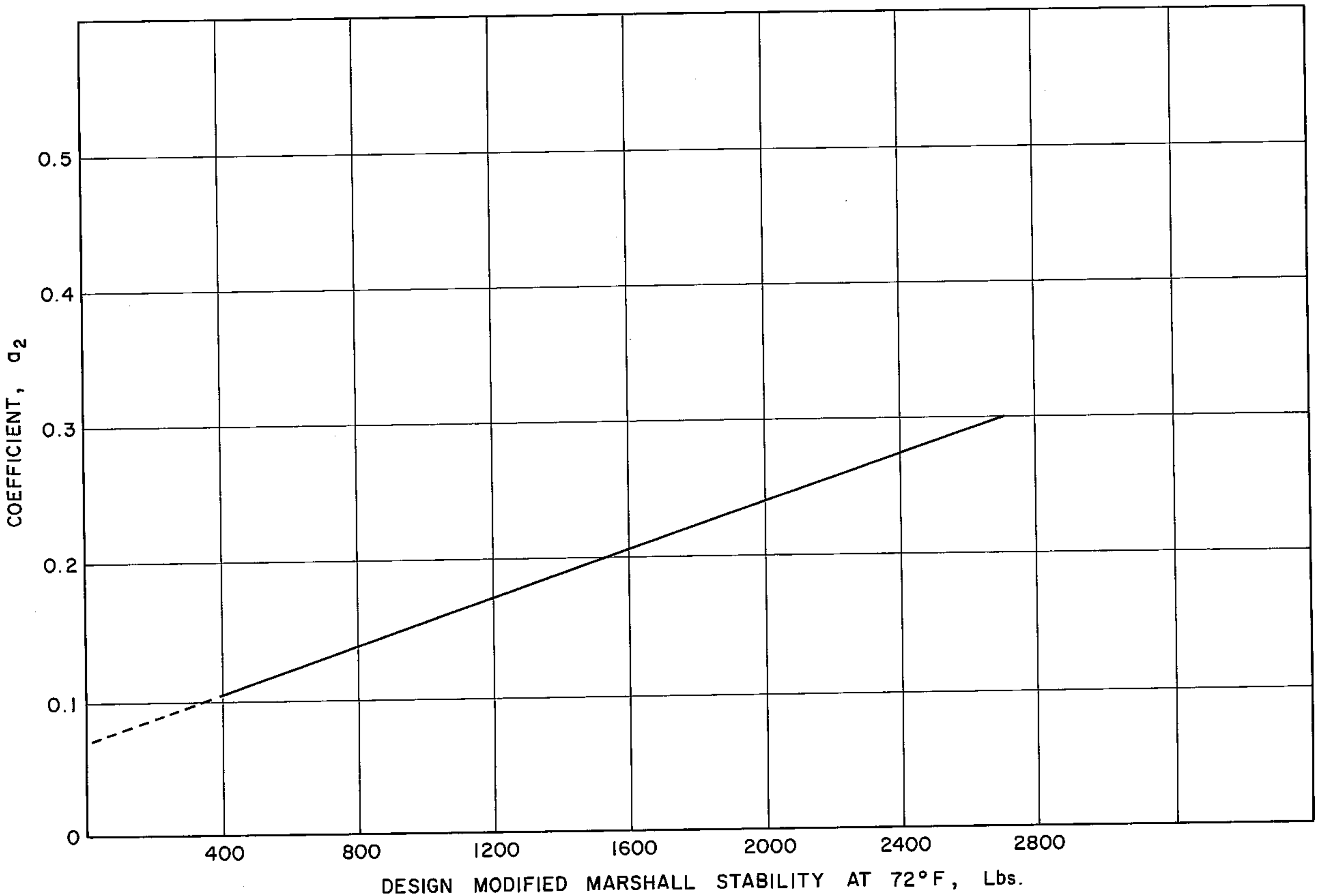


Figure 9.

Inspection of the preceding, however, indicates that the dry modified Marshall stability terms cancel out and the relationship can be simplified to the following form:

$$MS_{Design} = CF(MS_m)$$

where

MS_{Design}, MS_m and CF are as previously defined

Since the IHR-505 researchers recommend a CF=2.0 for typical Illinois environmental conditions (where the base course is constructed during a May-through-September period and left unsurfaced for 7 days), the MS_{Design} relationship simply becomes as follows:

$$MS_{Design} = 2.0(MS_m)$$

where

MS_{Design} = design modified Marshall stability

MS_m = soaked modified Marshall stability

This relationship is recommended for general design purposes.

Having determined the design modified Marshall stability value, the remaining step in determining structural coefficient, a_2, involves entering the horizontal axis of Figure 9 at the determined MS_{Design} value, extending a vertical line to the point of intersection with the diagonal line, and then reading the vertical ordinate (a_2 axis) at the intersection point.

The following example demonstrates the structural coefficient determination process.

Given: The structural coefficient values for a proposed EAM base course material having the laboratory mix characteristics as shown in Table 5 is to be determined.

1. Convert the reported soaked modified stability value of 1050 lbs. to a design modified Marshall stability value as follows:

$$\begin{aligned} MS_{Design} &= 2.0\ (MS_m) \\ &= 2.0\ (1050) \\ &= 2100 \text{ lbs.} \end{aligned}$$

TABLE 5. EMULSIFIED ASPHALT DESIGN MIXING FORMULA PASSING

DESIGN NO.: 01

RECOMMENDED MIXING FORMULA:

From the data we recommend that these ingredient materials be proportioned to produce a mixture having the following approximate composition:

	Percent	Specification
Passing 1½ inch sieve, %	100	100
Passing 1 inch sieve, %	95.1	90-100
Passing inch sieve, %		
Passing ½ inch sieve, %	84.2	60-90
Passing No. 4 sieve, %	43.9	30-56
Passing No. sieve, %		
Passing No. 16 sieve, %	13.2	10-40
Passing No. sieve, %		
Passing No. 200 sieve, %	5.7	4-10
*Bitumen, % by wt. of dry agg.	7.0 (4.0 residual)	

The gradation given above is that which resulted from the combination of the ingredient materials submitted to the laboratory and is not necessarily the optimum gradation.

*A slight adjustment in the asphalt may be necessary after the job starts.

	Percent
Recommended Moisture for Mixing*	4
Recommended Moisture for Compaction*	4
Percent of Residual Asphalt in Emulsion	57

Mix Parameters	Value at 4 Percent E.A.	Limiting Critieria
Percent Stability Loss	5	50 max.
Total Voids	7.6	2-8
Percent Moisture Absorption	2.2	4 max.
Soaked Mod. Stability (72° F.)	1050	500 min.
Percent Aggregate Coating	80	50 min.

*by weight of dry aggregate

2. Enter the figure provided for converting design modified Marshall stability coefficient, a_2, at 2100 lbs., extend a vertical line to the point of intersection with the diagonal line, then read the coefficient value as a_2=0.25 on the vertical axis. Figure 10 demonstrates this procedure.

MINIMUM DESIGN REQUIREMENTS AND LIMITATIONS

The Illinois flexible pavement design procedure contains minimum thickness and material strength requirements for each layer of the pavement structure. These considerations have been established to avoid the possibility of developing impractical designs. The minimum strength requirements are increased as the structural design requirements increase. It is equally important that such minimum requirements be established for the use of EAM as a base course.

While EAM base course materials can have similar strength potentials to many hot-mix asphalt-stabilized materials, they have one significant difference--slower strength gain. Hot-mix materials exhibit their final strength potential as soon as cooled (hours), while properly designed cold-mix materials require up to 3 years of field curing to reach final cured strength. This basic difference makes the latter subject to premature performance losses under early high traffic volume loading conditions. This limitation suggests that either posting traffic restrictions in the early years of the design life or limiting Structural Number (indirectly Traffic Factor) requirement should be considered. The latter is considered as the more desirable approach and is recommended.

The IHR-505 findings indicate two significant points germane to the establishment of a limiting Structural Number requirement, the first being that after a 7-day dry field curing period a properly designed EAM base will provide greater load-carrying capacity than non-stabilized granular materials. Secondly, strength gains of EAM bases are fairly rapid during the first year, reaching 70-75 percent final cured strength, and then continue to increase more slowly, with final cured strength normally not being completely achieved until after two to three years of field curing.

This suggests obviously that EAM base use should extend beyond all situations permitting granular bases, but it does not fully define an upper limit. For the initial application of this procedure and until better information is obtained, EAM bases will be permitted in all pavement designs requiring Structural Numbers less than 4.50. This upper limit is premised on

COEFFICIENTS FOR EMULSIFIED ASPHALT - AGGREGATE BASE COURSE MIXTURES

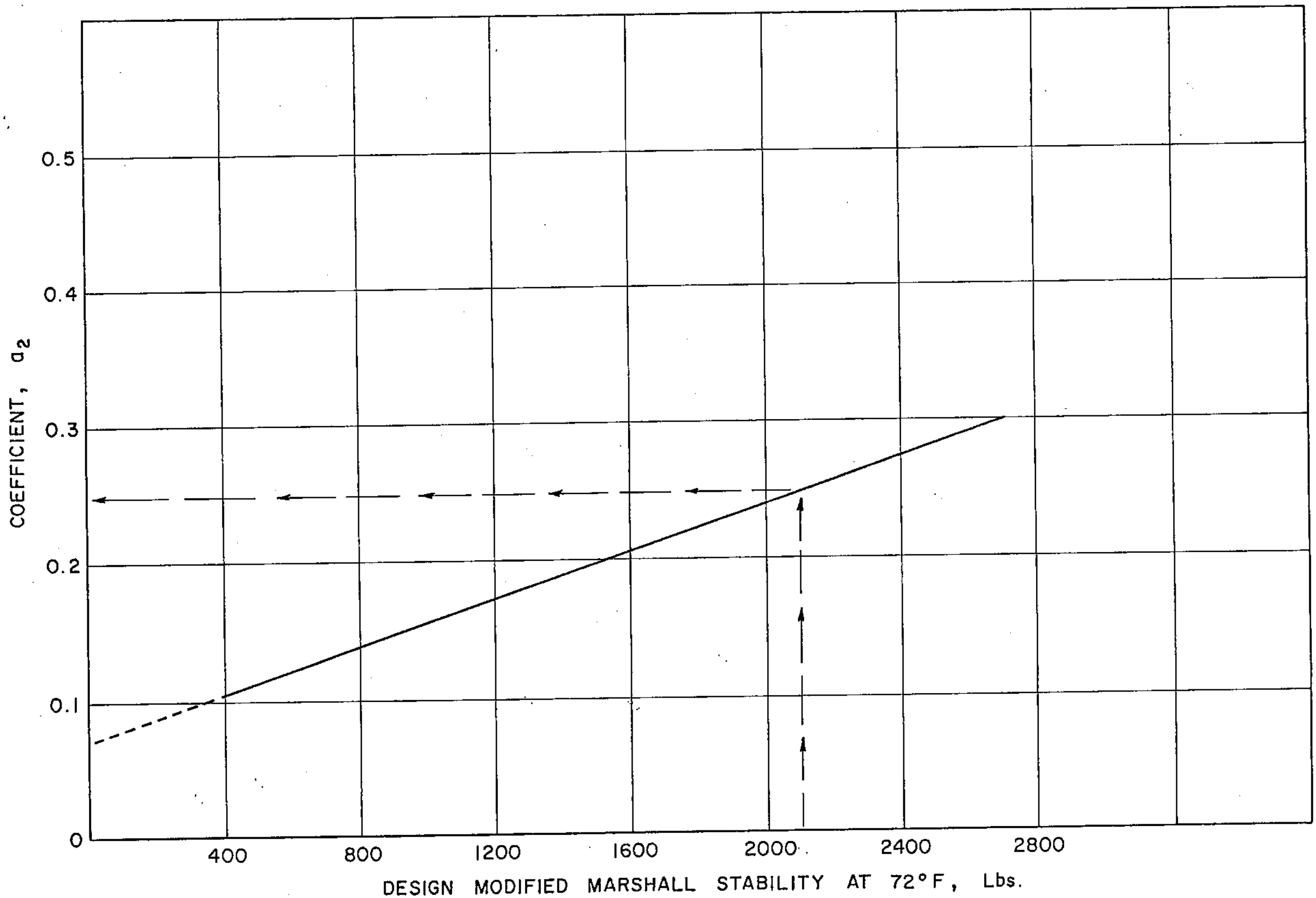


Figure 10.

the assumption that the one-year field strength of the EAM base should be sufficient to satisfy the structural design requirements. It is highly probable that a high-quality EAM base will achieve a one-year field strength of 2,000 to 2,100 lbs. This corresponds to an a_2 value of 0.24 to 0.25, and thus a Structural Number limit of less than 4.50.

It is further recommended that for pavement design purposes that the design modified Marshall stability value be the basis for determining base course thickness requirements. Specific recommendations involving minimum thickness and material requirements for EAM base course are presented in Table 6. Surface course and subbase requirements should remain as outlined in the Illinois flexible pavement design manual.

TABLE 6

MINIMUM THICKNESS AND MATERIAL REQUIREMENTS
FOR EAM BASE COURSE

Structural Number, D_t	Minimum Thickness Inches 1/	Minimum Design Modified Marshall Stability (lbs.)
1.00 to 1.99	6	1,000
2.00 to 2.49	6	1,000
2.50 to 2.99	7	1,000
3.00 to 3.49	8	1,300
3.49 to 3.99	8	1,900
4.00 to 4.49	8	2,100

1/ When an EAM with a strength greater than the minimum required above is used, a reduction in the minimum required thickness, up to a maximum of 1 inch, will be allowed.

TABLE 6

MINIMUM THICKNESS AND MATERIAL REQUIREMENTS
FOR EAM BASE COURSE

Structural Number, D_t	Minimum Thickness Inches 1/	Minimum Design Modified Marshall Stability (lbs.)
1.00 to 1.99	6	1,000
2.00 to 2.49	6	1,000
2.50 to 2.99	7	1,000
3.00 to 3.49	8	1,300
3.49 to 3.99	8	1,900
4.00 to 4.49	8	2,100

1/ When an EAM with a strength greater than the minimum required above is used, a reduction in the minimum required thickness, up to a maximum of 1 inch, will be allowed.

TABLE 6

MINIMUM THICKNESS AND MATERIAL REQUIREMENTS
FOR EAM BASE COURSE

Structural Number, D_t	Minimum Thickness Inches 1/	Minimum Design Modified Marshall Stability (lbs.)
1.00 to 1.99	6	1,000
2.00 to 2.49	6	1,000
2.50 to 2.99	7	1,000
3.00 to 3.49	8	1,300
3.49 to 3.99	8	1,900
4.00 to 4.49	8	2,100

1/ When an EAM with a strength greater than the minimum required above is used, a reduction in the minimum required thickness, up to a maximum of 1 inch, will be allowed.